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APPLICABILITY OF THE ATMOSPHERIC WATER GENERATION: THE CASE OF HOTEL INDUSTRY IN SRI LANKA

P.M. Wijesundara[1], Chandanie Hadiwattage[2] and G.G.N. Chandani[3]

ABSTRACT

The proliferation of plastic drinking water bottles poses significant environmental, economic, and social challenges globally. In response, many countries are seeking alternative methods to provide safe drinking water. Atmospheric Water Generators (AWGs) have emerged as a promising solution, yet their implementation remains novel, particularly in countries like Sri Lanka. This paper explores the feasibility of implementing AWGs in the hotel industry in Sri Lanka to mitigate reliance on bottled water. Through a comprehensive literature review and quantitative research methodology including questionnaire surveys, the functional requirements, constraints, drivers, barriers, and strategies for AWG implementation were identified and analysed. The findings underscore the critical importance of factors such as low relative humidity, wide temperature range functionality, energy efficiency, water quality, and appropriate design in selecting AWGs. While drivers like higher efficiency, governmental support, and public awareness propel AWG adoption, barriers such as high initial investment, energy consumption, and mineral deficiency pose challenges. Strategies to overcome these barriers include lifecycle cost analysis, renewable energy integration, vendor selection, and mineral supplementation. The research contributes to understanding successful AWG implementation in the Sri Lankan hotel industry, addressing water bottle consumption's environmental and socio-economic impacts. This study highlights the urgency of transitioning to sustainable water solutions and provides practical insights for stakeholders to navigate the implementation of AWGs effectively.

Keywords: *Atmospheric Water Generators; Bottled Water Consumption; Drinking Water; Drivers and Barriers; Hotels; Sri Lanka; Strategies.*

1. INTRODUCTION

Drinking-water is essential for survival, and everyone should have access to an appropriate, clean, and readily available supply (Chang, 2015). Improving the quality of drinking-water is a significant concern to protect human health globally (Garfí et al., 2016). World Health Organisation (WHO, 2019) stated that in 2017, 71% of the world's population (5.3 billion people) relied on an adequately regulated drinking-water system, which is on-site, accessible when required, and free of contamination.

[1] Researcher, Department of Building Economics, University of Moratuwa, Sri Lanka, pavithrawijesundara.pw@gmail.com
[2] Senior Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, chandanieh@uom.lk
[3] Lecturer, Department of Facilities Management, University of Moratuwa, Sri Lanka, navodag@uom.lk

The current trend of drinking-water from bottles reveals remarkable adaptation in each part of the world, varying with geographical location, lifestyle, needs, and comfort of people in nature, and the theme behind these kinds of societal changes is the scarcity of contaminated water and its effect on human health and livelihood results (Dasinaa & Delina, 2015). Further, the authors mentioned that, in Sri Lanka, the Western Province has a higher percentage of people involved in the handling of bottled water than the other provinces. Still, in recent years, the Southern and Central Provinces have played a vital role over the Eastern Province. Every minute, a million plastic bottles are purchased worldwide, and resulting in an environmental crisis that some activists say will be as bad as climate change (Laville & Taylor, 2017). Toxic chemicals are released as the plastic degrades over hundreds of years, potentially contaminating groundwater (Fresh Outlook Foundation (FOF, 2021). Feng (2019) stated, according to an estimate is done by an expert for Eco-Business amid many anti-plastic announcements by major hotel chains, a single 200-room four-star hotel will use around 300,000 pieces of single-use plastic in a month if it is at total capacity and does not invest in any eco-friendly alternatives. About 20,000 plastic water bottles per month are used in a single 200-room four-star hotel (Feng, 2019). When considering the cost, bottled water is about more expensive per gallon than tap-water. Water harvesting has been done in various ways worldwide, including desalination, groundwater harvesting, and rainwater capture and storage. Liquid water must already be sufficient for this to operate, but when such sources are scarce, atmospheric water generating becomes necessary (Jarimi et al., 2020). The atmosphere contains a large amount of water in the form of vapour, moisture, and other states. This amount of water can be used with the help of an Atmospheric Water Generator (AWG) (Tripathi et al., 2016). AWG stands out as a significant advancement that can address the issue of pure water shortage by generating liquid water from the air (Shourideh et al., 2018). Air is a cleaner platform than soil, and water production from the air eliminates the need for groundwater pumping and the fear of soil contamination; because of that, the quality and taste of the water that is processed using air-to-water technology is of the highest standard (Watergen, 2024). Besides that, Akvo (2018) elaborates that atmospheric water generators are cost-efficient devices.

Currently, the Sri Lankan hotels does not use AWGs for their water needs. Instead, hotels primarily rely on bottled water to ensure a safe and reliable supply of drinking water for their guests, posing considerable environmental and economic concerns. AWGs provide an extended solution to the growing problem of water scarcity. AWGs generate water from the atmosphere, reducing dependency on traditional sources and eliminating the need of plastic bottles. They deliver reliable, high-quality water while resolving environmental concerns and cutting expenses. Implementing AWGs can improve sustainability and assure a consistent supply of safe drinking water in Sri Lankan hotels.

2. LITERATURE FINDINGS

2.1 ATMOSPHERIC WATER GENERATORS

The atmospheric water generator is a device that harvests water from the humidity in the air using dehumidification/condensing technology (Tripathi, et al., 2016). Dehumidification is the process of removing vapour from gas-vapour combination, specifically the separation of water vapour molecules from ambient air in this project (Bolsinger & Ralphs, 2019). AWG uses the principle of latent heat to convert water vapour molecules into water droplets. Therefore, it works on the similar principle that is used in refrigerators and air conditioners, the principle of cooling through evaporation (Tripathi, et al., 2016). The atmospheric air that consists of vapour pass several filters while entering the AWG. Then the water vapour in the air condenses to water drops because the surface temperature of the evaporator is lower than the dew point temperature of the atmosphere (Balaganapathi, et al., 2020). The condensate water accumulates in the water collector and drains to the bottom tank for storage and activated Carbon and reverse osmosis treatments, Ultra-Violet (UV) sterilisation, and a couple of other processes to make this water portable and drinkable (Eastern Research Group, 2018).

2.2 BENEFITS OF THE AWG

Water scarcity solutions include various water-saving measures, reclaiming used water, and water production (Inbar, et al., 2020). The authors stated that atmospheric water production is an efficient and eco-friendly source of potable drinking-water. Some of the benefits of using AWG are briefly described below.

Energy-efficiency **-** AWG is more energy-efficient than the other feasible methods available in the modern world (Elliott, 2021). AWG uses most solar energy and battery backup as the primary source, and it will reduce the high energy consumption (James, et al., 2018).

Less environmental impact **-** Atmospheric air is a renewable source of energy; due to the temperature, different AWG will be able to produce the water without producing waste (Moghimi, et al., 2021). When considering the water bottles, it is stored mostly in PET-type bottles, but there is no problem with AWG (Smuts, 2015). Delgado (2020) stated that the AWG creates water on demand, reducing the requirement for plastic storage containers that would otherwise end up in a landfill or river.

Cost-effectiveness **-** According to the case study of Eastern Research Group (2018), when comparing the cost per 1 litre of bottled water and AWG, AWGs require more upfront capital compared to bottled water. Still, when considering the entire useful life of the AWG unit, it is lower than the bottled water (AWG total cost per 1litre - $ 0.07-0.14 and bottled water total cost per 1 litre - 0.38).

Water quality **–** AWG has a decentralised production method; therefore, the diseases are borne, and contaminants of existing water sources will not spread (Moghimi, et al., 2021). The water generates from AWG is microbiologically safe, which means it is free from potentially harmful contaminants because it has both UV, air filtration, and other kinds of different filtration methods (Brigano & Kapustin, 2021).

No-water transport infrastructure required - Another benefit of using atmospheric water as a source of drinking-water is that no water-transport infrastructure is required; harvesting equipment can be put practically everywhere (away from the coastline) (Inbar, et al., 2020).

2.3 REQUIREMENTS AND CONSTRAIN TO BE CONSIDERED WHEN SELECTING THE AGW

There are some factors to be considered when selecting AWG (Moradi, 2019). According to Moradi (2019), the main factors are the need for and availability of a high percentage of Relative Humidity (RH) in the air and air temperature and the AWG's geological area.

Correspondingly, Moradi (2019) mentioned that yield and cost are two other factors that should be considered

Table 1: Requirements and constraints to be considered when selecting an AWG

Factor	Unit of measure
Functional Requirements	
Should be used when the RH is low.	30% RH
Should utilise about the same amount of power as a typical industry appliance.	<1000W
Should be able to provide adequate water for the facility.	>200 litres per day
Alternative energy sources should be used to power it.	Using power other than electricity
Water should be filtered, and minerals added	At least one filter and mineral adder
Design should be appropriate for the facility	According to the client requirement
Functional Constraints	
To draw moisture, air should be used.	No input of water to the machine is needed
The water produced should meet EPA standards in terms of quality.	TDS[2] < 500 ppm pH ~8
Operation processes should be safe	No hazardous/ harmful elements or parts
Should be operated at a low volume.	< 50 dB
Minimum production costs are required	Depending on the organisation

Adapted: (Moradi, 2019)

2.4 DRIVERS AND BARRIERS RELATED TO THE AWG IMPLEMENTING PROJECT

Drivers and barriers to implantation are presented in Table 2.8. These details elaborate according to the countries that already use AWG, since it will help evaluate drivers and barriers regarding the Sri Lankan context.

Table 2: Drivers and Barriers of the AWG implementation

Drivers and Barriers	Sources
Driver	
Higher efficiency with lower environmental impact	(Market Research Team, 2021)
Declining freshwater level	
Supportive government regulations (FCAU)	
Several governments throughout the world have expressed an interest in developing infrastructure for commercial atmospheric water purposes.	(Market Research Team, 2021)
Growing adaptation for alternative water sources	(Kulkarni, 2019)
The power supply can be shifted to renewable energy (Ex. Solar)	
Should be able to produce water continually for drinking purposes anywhere that have sufficient RH%	(Maida, 2019)

Drivers and Barriers	Sources
Driver	
Increased public awareness of waterborne diseases and the legislation that governs them.	(Dublin, 2020)
User-friendly technological advancement and future growth opportunities	
Development in novel technologies in AWGs (advanced filtration systems, electrically improved harvesting, advanced Oxidation processes, and automatic variable filtration technology)	(Industry ARC, 2019)
AWGs are becoming more common in a variety of end-use industries.	
The demand for AWG is predicted to increase significantly because of Asia's scarcity and depleted freshwater resources.	(IPS News Agency, 2020)
Barriers	
The high initial investment for implementing	(Market Research Team, 2021)
Cooling condensation systems require high amounts of grid electricity	
Not sufficient to use for all water requirements such as laundry, gardening, etc.	(Zhou, Lu, Zhao, & Yu, 2020)
To maintain and operate inside of the AWG, expert knowledge is needed.	
No proper system to balance the requirement of moisture concentration and water release.	
Difficulty in choosing a suitable vendor for purchasing the AWG	(The United Abrahamic Family, 2019)
AWG's do not work in every climate type	
Difficulties in obtaining approval from the top management board	
Lack of minerals compared to the groundwater.	

3. RESEARCH METHODOLOGY

A quantitative approach was selected to achieve research objectives. The Quantitative research entails gathering and analysing numerical data objectively to characterise, predict, or regulate factors of interest, and it aims to explore causal correlations between variables, make predictions, and generalise findings to a larger group of people (McLeod, 2019). This research design includes a comprehensive literature review, questionnaire surveys, data analysis, and discussion of research findings, respectively. The questionnaire survey was conducted to gather the details on the negative impacts of water bottle usage and the overall idea of implementing AWG in the Hotel industry in the Sri Lankan context. Due to the lack of realistic practices of the AWG in Sri Lanka, the main concern of the questionnaire survey was to validate the information identified in the literature review regarding the global context. The sample was chosen to include 30 professionals working in up to 3-star hotels across various districts, specifically targeting those in executive and managerial positions with extensive experience in the hotel industry for a questionnaire survey. This selection was made to ensure the insights gathered are from individuals with substantial industry knowledge and expertise. Professionals at these levels are typically responsible for strategic decision-making and have a comprehensive understanding of both operational challenges and opportunities within their hotels. Their extensive experience ensures that the feedback and data collected are reliable, informed, and reflective of the industry's best practices and current trends. Due to the study is going to investigate the applicability of implementing the AWG in Hotels, separate opinions from different hotels in several districts were collected. The demographic distribution of the survey respondents is shown in Table 3.

Table 3: Demographic Distribution of Survey Respondents

Variable	Categories	Frequency	Percentage
District	Anuradhapura	2	6.7
	Batticaloa	3	10
	Colombo	8	26.7
	Galle	2	6.7
	Hambantota	1	3.3
	Kalutara	3	10
	Kandy	2	6.7
	Matale	3	10
	Matara	2	6.7
	Nuwara Eliya	1	3.3
	Puttalam	2	6.7
	Trincomalee	1	3.3
Experience	Less than 5	2	6.7
	5 – 10	10	33..3
	10 - 15	13	43.3
	More than 15	5	16.7

The table presents the distribution of professionals participating in a questionnaire survey, categorised by the district they work in and their years of experience in the hotel industry. The percentage column in the table indicates the proportion of total respondents for each category within the "District" and "Experience" variables. The Relative Importance Index (RII) was utilised to analyse the significance of various factors related to the adoption of AWGs in the Sri Lankan hotel industry. Respondents rated each factor on a scale from 1 to 5, with 1 indicating "highly disagree" and 5 indicating “highly agree”. The RII was calculated using the formula RII = $\sum W / A \times N$ where W represents the weight given to each factor, A is the highest weight on the scale (5), and N is the total number of respondents (30). This analysis provided a quantitative measure of each factor's significance, aiding in strategic decision-making for the implementation of AWGs in hotels.

Table 4: Importance Levels Based on the RII Value Range

Maximum RII value	RII Value Range	Importance Level
1	1.0 – 0.8	High
0.8	0.8 – 0.6	Significant
0.6	0.6 – 0.4	Moderate
0.4	0.4 – 0.2	Low

4. RESEARCH FINDINGS AND ANALYSIS

4.1 FUNCTIONAL REQUIREMENTS AND CONSTRAIN OF IMPLEMENTING AWG

According to the literature review, there were functional requirements and constraints when implementing the AWGs in any location. Tables 4 and 5 are illustrated the responses with the percentages and the status of critical or non-critical gathered from the questionnaire survey.

Table 5: Critical or non-critical status of the identified functional requirements

Functional Requirements	Percentages (%)		Critical or Non-critical Status
	Critical	Non-Critical	
Should be used when the RH is low	100	-	Critical
Should be able to function at a wide range of temperatures	96.67	3.33	Critical
Should utilise about the same amount of power as a typical industry appliance	100	-	Critical
Should be able to provide adequate water for the facility	100	-	Critical
Alternative energy sources should be used to power it	100	-	Critical
Water should be filtered, and minerals added	100	-	Critical
Design should be appropriate for the facility	73.33	26.67	Critical

Table 6: Critical or non-critical status of the identified functional constraints

Functional Constraints	Percentages (%)		Critical or Non-critical Status
	Critical	Non-Critical	
To draw moisture, air should be used	100	-	Critical
Should be able to generate water within a specific temperature range	100	-	Critical
The water produced should meet EPA standards in terms of quality	86.67	13.33	Critical
Operation processes should be safe	100	-	Critical
Should be operated at a low volume	96.67	3.33	Critical
Minimum production costs are required	100	-	Critical

4.2 DRIVERS FOR IMPLEMENTING AWG AT HOTEL INDUSTRY

As identified in the literature review, there are several drivers to implement the AWG in hotels in the Sri Lankan context. Figure 1 presents the graphical representation of the drives.

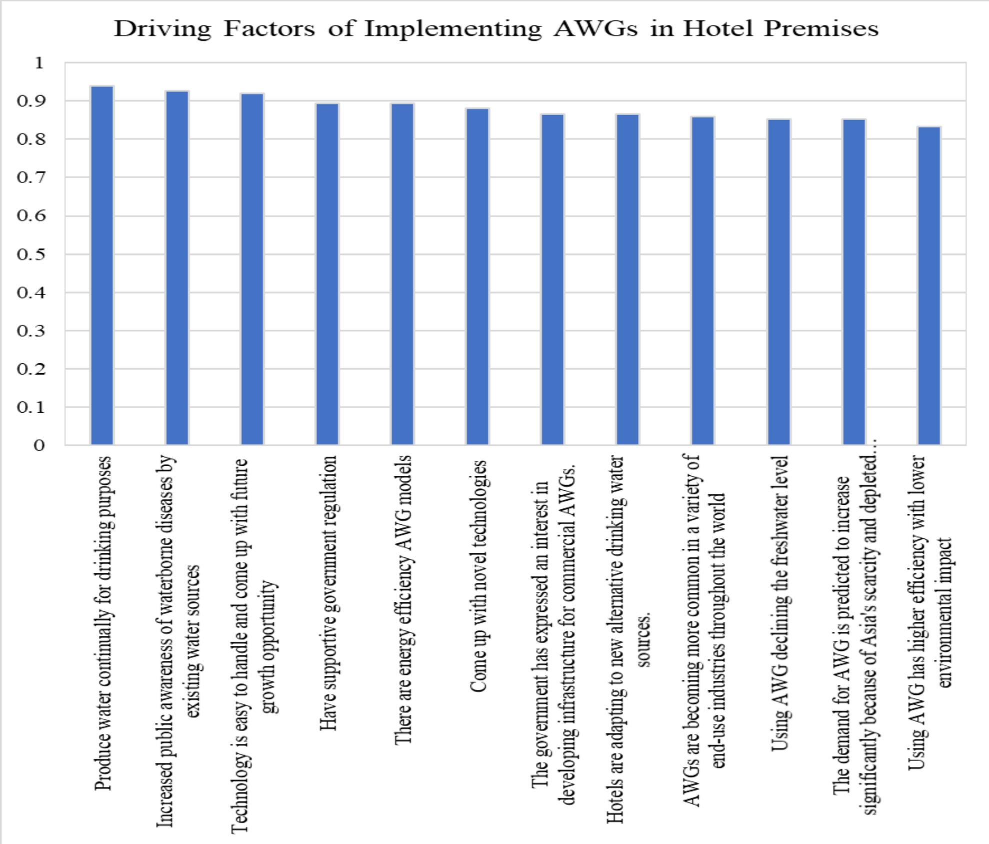

Figure 1: Driving factors of implementing AWGs in hotel industry according to the RII value

The survey exposed that "Produce water continually for drinking purposes" as the most important driver to implement AWG in hotels. As the alternative for the drinking-water bottles, providing the required capacity of water continually is an essential driver for hotels and AWG can fulfil that goal. According to Moghimi et al. (2021), AWGs offer an alternative water resource, especially in water-scarce regions. The second one is "Increased public awareness of waterborne diseases by existing water sources". These strategies focus on improving water quality, sanitation, and hygiene practices (Kumar et al., 2022). Not awareness of water treatments methods and water sources of water bottles and other alternatives of drinking-water, makes the requirement of well-known treated water. Since the AWG can provide fresh water without waterborne diseases, it will be great a solution for the alternative method for hotels. "Technology is easy to handle and come up with future growth opportunity" was ranked as the third driver. Sadowski et al. (2023), stated that AWGs extract water from the air using refrigeration, sorption, or fog harvesting technologies. Their ease of operation makes them accessible to a wide range of users, even after reading the user manual. The literature review identified twelve key drivers for implementing AWGs, which can be categorised into opportunities and strengths for hotels. These drivers include supportive government regulations and the development of energy-efficient AWG models, as noted by Sadowski et al. (2023). Governments are increasingly recognising the importance of AWGs for a sustainable water supply and expressing interest in developing infrastructure for commercial AWGs. Technological advancements such as advanced filtration systems, electrically improved harvesting, advanced oxidation processes, and automatic variable filtration technology are also driving the adoption of AWGs. Hotels are adapting to new alternative drinking-water sources, benefiting from AWGs' reliable on-site water production, which reduces dependence on external sources (Banerjee et al., 2023). AWGs are becoming more common across various end-use industries worldwide, including residential buildings, military installations, disaster relief efforts, remote communities, and industrial facilities, as highlighted by Inbar et al. (2020). The utilisation of AWGs helps mitigate the decline in freshwater levels by providing an additional water source, with their efficiency depending on climatic conditions and technology (Potyka et al., 2024). The demand for AWGs is expected to increase significantly in Asia due to the region's severe freshwater scarcity (Zia, 2020). Furthermore, AWGs offer higher efficiency with lower environmental impact, with all identified drivers having high importance levels according to the RII ranges, indicating their critical role in the successful implementation of AWGs. All the above drivers have higher rates of RII (<0.83). That means, all drivers identified have high importance levels according to the RII ranges.

4.3 BARRIERS FOR IMPLEMENTING AWG IN HOTEL INDUSTRY

As well as drivers, several barriers were identified through the literature review. Figure 2 illustrates the graphical representation of the results of identified barriers.

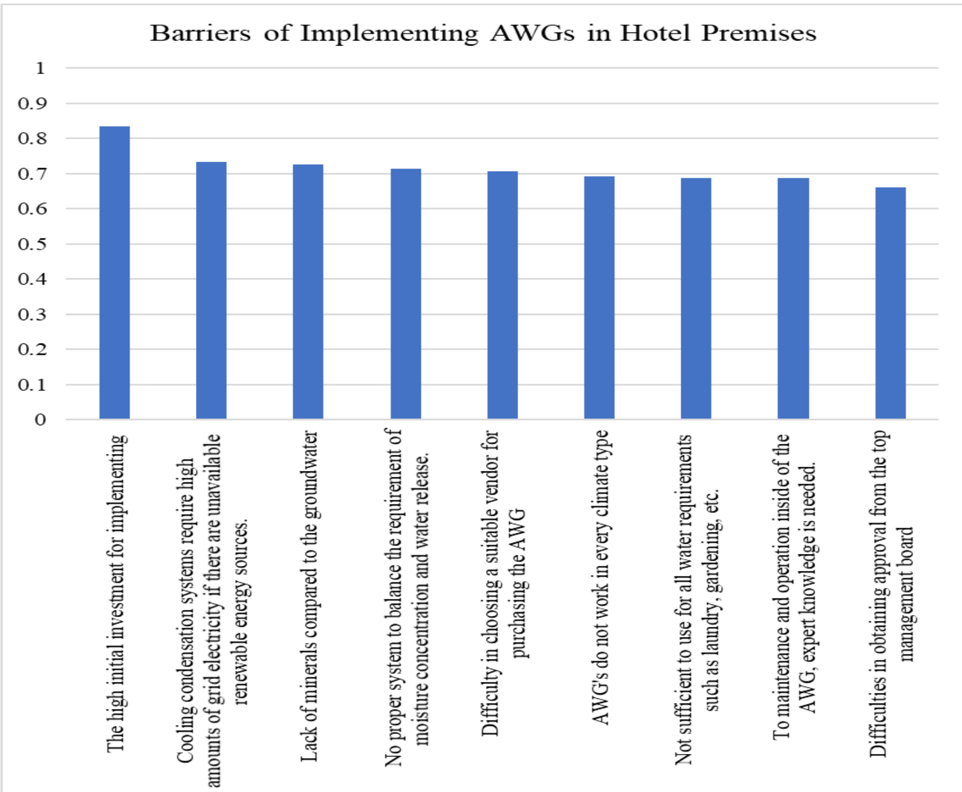

Figure 2: Barriers of implementing AWGs in hotel industry according to the RII value

"The high initial investment for implementing" is ranked as the most identified barrier (RII = 0.8333) among 9 barriers. This indicates that, high investment costs prevail as the most prominent barrier to the implementation of AWGs in hotels. The cost of buying the generator, transportation cost to the facility, and installing the solar power system for power generation are highly contributing to the initial costs. Therefore, it is clearly can be identified as the most important barrier, because when implementing a new strategy to mitigate an existing problem, that alternative should be more cost-effective than the previous method. However, assuming a perfect substitution between AWG machines and bottled water, the financial performance of AWG machines demonstrates an attractive substitute product in the majority of locations (Moghimi et al., 2021). 'Cooling condensation systems require high amounts of grid electricity if there are unavailable renewable energy sources" was ranked as the second barrier with RII value 0.7333. Cooling condensation AWGs use a compressor to cool the air and condense water vapor (Siddiqui et al., 2023). If renewable energy sources are unavailable, reliance on grid electricity can be high (Aravind, 2023). Using electrical power from the grid will increase the energy consumption because AWGs need to operate throughout the day and the condensing process needs a high amount of energy. Therefore, it will become another major obstacle to implementing the AWGs. As the third barrier, "Lack of minerals compared to the groundwater" was identified. Whether, AWG can provide fresh water, the percentages of the mineral required in drinking-water are not available in the atmosphere water vapour, when compared with the ground water. The mineral content in AWG water depends on the source air and the materials used in the system (Watergen, 2024). Some AWGs add essential minerals (such as calcium and magnesium) to improve water quality (drinkableair technologies, 2024). However, AWG water may still have lower mineral content compared to groundwater. The fourth and fifth barriers, "No proper system to balance the requirement of moisture concentration and water release" and "Difficulty in choosing a suitable vendor for purchasing the AWG" got the RII value of 0.7133 and 0.7067 respectively. Selecting a vendor for purchasing an AWG becomes a barrier because, as the newly invented strategy of making drinking-water, there are not many manufacturers and distributors in Sri Lanka.

The remaining barriers to implementing AWGs are notably significant but rated as moderate in importance compared to higher-level barriers. These barriers include the limitation that AWGs do not work in every climate type, as their performance is highly dependent on humidity and temperature (Sadowski et al., 2023). Consequently, not all regions would achieve the same level of water production due to these climatic constraints. Additionally, AWGs are not sufficient for all water requirements, such as laundry and gardening, because their capacity depends on factors like humidity levels and machine specifications. Maintaining and operating AWGs requires expert knowledge, including understanding system components, performing filter replacements, and troubleshooting. Furthermore, obtaining approval from top management boards can be challenging due to initial investment costs and operational considerations (Raveesh et al., 2023). These barriers have RII values between 0.7 and 0.6, indicating a significant level of importance.

4.4 STRATEGIES TO OVERCOME BARRIERS

To overcome the barriers of implementing AWGs in the Hotel industry in the Sri Lankan context, respondents were asked to suggest strategies. For the first barrier, it was suggested to analyse the overall life cycle cost comparison between bottled water consumption vs AWG. So, it will be easy to find the most cost-effective method between those two methods is. According to the case study of Eastern Research Group (2018), it was mentioned that there is a significant cost difference when considering the entire useful life of the AWG. Moreover, it can be used new technologies and manufacturing processes to minimise the overall production cost. When using the AWG, throughout the day it consumes a high amount of grid electricity and it will directly increase the operational cost of the AWG. Hence the respondent's suggestion was to implement the

AWGs with a solar power system. Due to the tropical country Sri Lanka always have solar power. In the hotel industry, there are plenty of other water requirements. However, this study is focused on drinking-water consumption, it is not needed to consider other water requirements like laundry, gardening, washrooms etc. Besides, respondents stated that as the first step, it is sufficient to fulfil the drinking-water consumption. Since AWG is a novel concept and technology to Sri Lanka, the respondents had not much knowledge about the maintenance and operation inside of the AWGs. Therefore, respondents did not suggest any strategy to overcome the issue. However, the AWG water generation project is similar to the HVAC system (Tripathi, et al., 2016). Therefore, by giving training to the technicians on the basic functions of AWG, it will be easy to mitigate the barrier. 'No proper system to balance the requirement of moisture concentration and water release', for this barrier also none of the respondents mentioned a strategy, due to the lack of knowledge of AWG's process. According to Zhou, et al. (2020), sorbent materials can be used as moisture harvesters if the water affinity is adjusted to allow for moisture concentration at low RH and water release with little energy input.

In Sri Lanka there are no details on who manufactured or distributed commercial type AWGs that can provide more than 1000 litres per day. Therefore, the strategy that was suggested by the respondent is to make contact with an international vendor to import AWGs. By referring to the feedback of previous customers, and doing the technical and commercial evaluations, suitable vendor can be selected. In literature synthesis it was identified that there are factors that need to be considered when selecting AWGs. According to the Eriksson and Hashemi (2008), there should be more than 30% RH levels and the temperature should be varied between 20℃ – 40 ℃. Respondents did not mention any strategy to overcome because Sri Lanka is a tropical country and the required level of RH and temperature levels are available in most of the areas in Sri Lanka. The average monthly RH level is higher than 70% and the mean annual temperature varies between 26.5℃ – 28.5℃ (Department of Meteorology, 2019). To implement a new strategy, it is a must to take approval from top management. As the first step, it is needed to prepare the proposal for the reason of implementing the AWG and submit it to the top management. Then discussed with them the drivers, and benefits that can be gained through the implementation. When compared to the ground water, there is a lack of minerals in atmospheric vapour. The remedy that was suggested by the respondents was to add minerals other nutrition to the generated water. According to Brigano and Kapustin (2021), there is an in-building filtration system in several AWGs and for others it can be added. Thus, to mitigate this barrier, the generated water should pump through the filters and then add minerals to the water to increase and maintain healthy pH levels.

5. CONCLUSIONS

The study underscores the significant potential of AWGs as an alternative to bottled water in Sri Lanka's hotel industry. Globally, there is a growing urgency to find sustainable drinking-water solutions, driven by the environmental impact of bottled water and the need for reliable water sources. In Sri Lanka, the adoption of new technologies has been relatively slow compared to more developed countries. The negative impacts of bottled water, such as the lack of transparency in water sources and treatment methods, and its high contribution to the carbon footprint, have led to a search for better alternatives. The AWG method has emerged as a promising solution. While many countries have begun implementing AWGs, this technology remains novel in Sri Lanka. Introducing AWGs to the hotel industry, which is a major consumer of bottled water, represents a strategic starting point. The research highlights the importance of addressing environmental conditions, efficiency, government support, and public awareness to facilitate the adoption of AWGs in Sri Lanka's hotel sector. Overcoming challenges like high initial costs, energy consumption, and maintenance requirements through incentives, collaboration, and education is crucial for the successful implementation of AWGs and promoting sustainable water management.

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